Evaluation of ASCAT-derived near-surface soil moisture by assimilation into the SIM model

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EUMETSAT H-SAF on Support to Operational Hydrology and Water Management

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ASCAT on MetOp

ASCAT:

- Real-aperture backscatter radar: C-band (5.255 GHz)
- MetOp launched late 2006 (data available from 2007)
- Observes $\sim$ 80% of the globe each day (two overpasses)
- 0.25° resolution

Soil moisture retrievals:

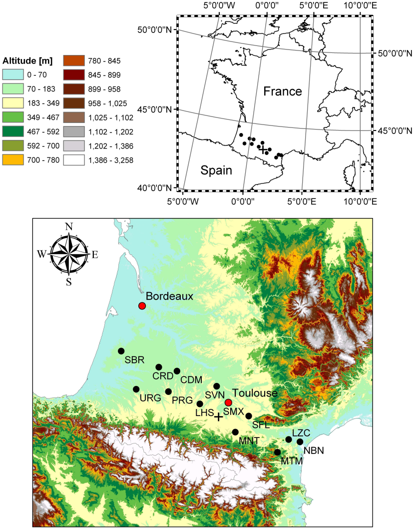
- Change detection approach, from TU-Wien (Wagner et al, 1999)
- Surface Degree of Saturation:
  - SDS=$(\theta - \theta_{min})/(\theta_{max} - \theta_{min})$
- Near-surface observation only, $\sim$ 1 cm
- Operationally supported via EUMETCAST
  - Assimilated into ECMWF's IFS

Evaluating the ASCAT SDS

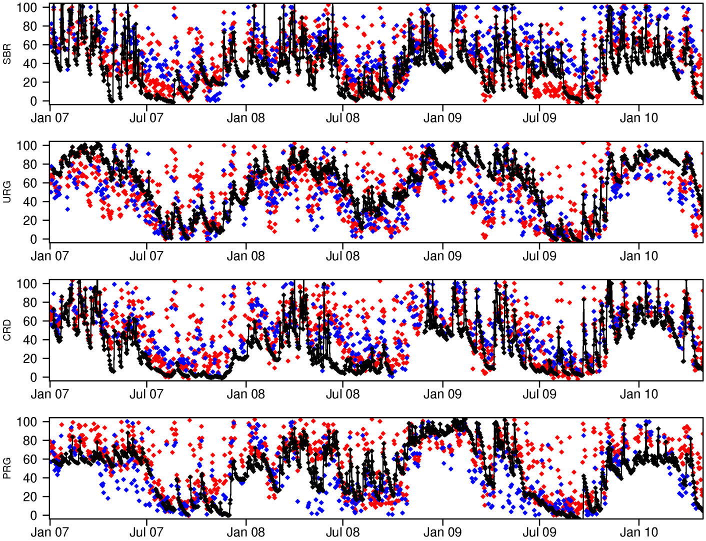
- Comparison to in situ observations from SMOSMANIA
- Comparison to soil moisture from the SIM modeling suite over France
  - **S**AFRAN: atmospheric analysis $->$ forcing for ISBA
  - **I**SBA: land-surface model $->$ surface energy and moisture fluxes
  - **M**ODCOU - hydrogeological model $->$ routes moisture fluxes through river network
- Assimilation into SIM
  - Assimilate into near-real time SIM chain
  - Assess against delayed cut-off SIM chain (3000 additional observing stations)
    - More accurate SAFRAN forcing -> more accurate surface hydrology
  - Test impact on simulations of soil moisture, fluxes, and river discharge

Comparison to SMOSMANIA in situ soil moisture

SMOSMANIA monitoring network



Timeseries at SMOSMANIA sites



SDS (% of saturation) from in situ (black), SIM (red), ASCAT (blue)

SMOSMANIA statistics

	SIM / SMOSMANIA			ASCAT / SMOSMANIA			ASCAT / SIM		
	r_{abs}	r_{anm}	RMSD (%)	r_{abs}	r_{anm}	RMSD (%)	r_{abs}	r_{anm}	RMSD (%)
SBR	**0.81**	**0.72**	**19.0**	0.73	0.65	31.2	0.74	0.71	25.5
URG	0.67	0.68	23.7	**0.83**	**0.74**	22.0	0.79	0.68	**17.5**
CRD	0.72	0.56	25.2	0.78	0.59	27.1	**0.84**	**0.71**	**16.2**
PRG	0.67	0.43	21.9	0.70	0.57	21.6	**0.78**	**0.72**	**19.8**
CDM	0.74	0.57	**19.6**	0.63	0.62	26.5	**0.75**	**0.76**	20.8
LHS	**0.70**	0.43	**22.4**	0.65	0.56	25.9	0.68	**0.72**	23.4
SVN	0.71	0.56	22.1	0.70	0.58	22.4	**0.77**	**0.72**	**18.7**
MNT	0.62	0.56	24.0	0.62	0.58	27.3	**0.71**	**0.66**	**21.7**
SFL	0.73	0.47	20.4	0.60	0.53	28.9	0.70	**0.68**	23.9
MTM	**0.61**	**0.54**	31.2	0.35	0.35	40.1	0.35	0.35	**25.5**
LZC	0.73	0.69	18.4	**0.78**	**0.78**	**16.4**	0.73	0.66	19.6
NBN	0.66	0.56	20.3	0.68	0.61	26.2	**0.75**	**0.68**	**19.7**

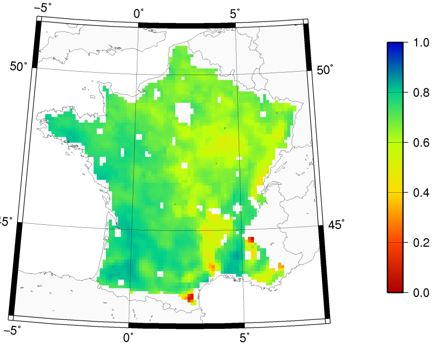
r_{abs} - absolute correlation

r_{anm} - anomaly correlation (relative to 31-day moving average)

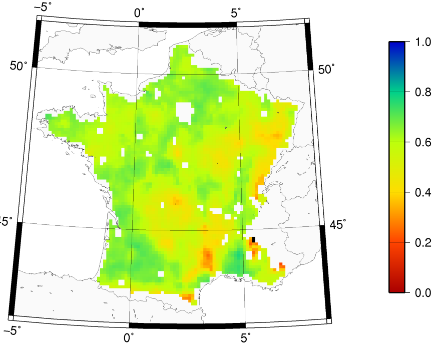
RMSD - Root Mean Square Difference

Comparison to SIM near-surface soil moisture

SIM & ASCAT correlations

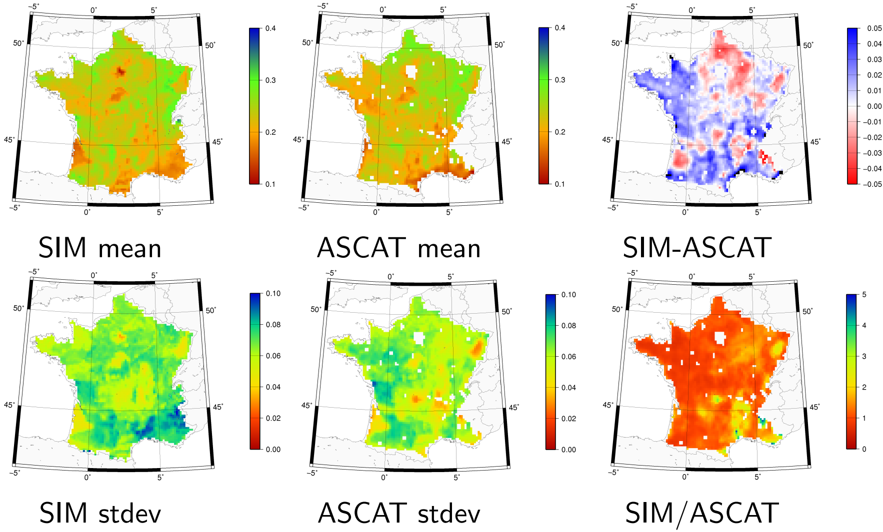


r_{abs}
mean: 0.69
87% grids > 0.6



r_{anm}
mean: 0.62
77% grids > 0.6

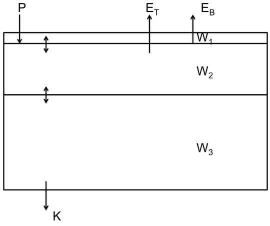
SIM & ASCAT abs. values (m^3m^{-3})



Assimilation of ASCAT into SIM

Interactions between Surface, Biosphere, and Atmosphere (ISBA)

- Three-layer force-restore model:



- w_1 - near-surface soil moisture
  bare soil evap., ∼1 cm
- w_2 - root-zone soil moisture
  transpiration, ∼ 0.5-2 m
- w_3 - deep-layer soil moisture
  deep layer storage, ∼ 1-3 m

- Observations: $\mathbf{y} = [w_1]$
- Update vector: $\mathbf{x} = [w_1, w_2]$

The Simplified EKF (1-D)

State forecast:

$$\mathbf{x}^b(t_i) = \mathcal{M}_{i-1}[\mathbf{x}^a(t_{i-1})]$$

State update:

$$\mathbf{x}^a(t_i) = \mathbf{x}^b(t_i) + \mathbf{K}_i \left(\mathbf{y}_i^o - \mathcal{H}_i[\mathbf{x}^b(t_i)] \right)$$

Kalman gain:

$$\mathbf{K}_i = \mathbf{P}_0 \mathbf{H}_i^T \left(\mathbf{H}_i \mathbf{P}_0 \mathbf{H}_i^T + \mathbf{R_i} \right)^{-1}$$

$\mathbf{x}^a$ - analyzed state vector
$\mathbf{x}^b$ - background state vector
$\mathbf{y}^o$ - observation vector

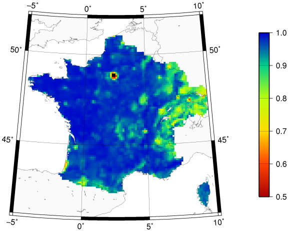
$\mathbf{P}_0$ - model background error matrix
$\mathbf{R}$ - observation error matrix

$\mathcal{H}$ ($\mathbf{H}$) - obs. operator (linearized)
$\mathcal{H}$ is a 24 hour ISBA forecast

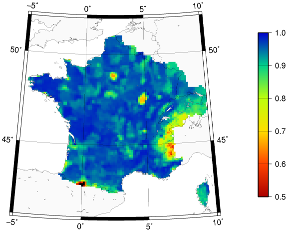
Assimilation experiments

- Assimilate ASCAT SDS from January 2007 - May 2010 (SIM_ASCAT)
  - Used descending (early morning) overpass only
  - CDF-match ASCAT to SIM climatology (3.5 years)
- Assimilate into near-real time chain (SIM_NRT)
- Assess against delayed cut-off (climatological) chain (SIM_DEL)

Difference in w_2 from SIM_NRT & SIM_DEL



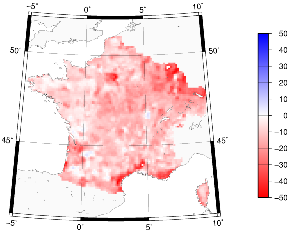
r_{abs}
mean: 0.95



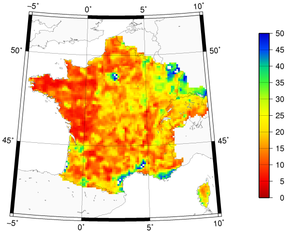
r_{anm}
mean: 0.94

- Temporal behavior is very similar
- Very difficult for the assimilation to improve

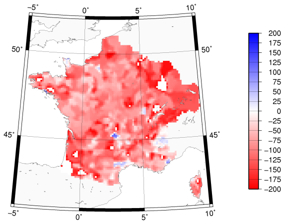
Difference in w_2 from SIM_NRT & SIM_DEL



w_2 bias (mm)
mean: -13 mm



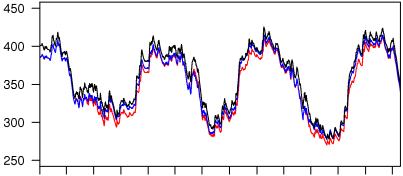
RMSD (mm)
mean: 18 mm



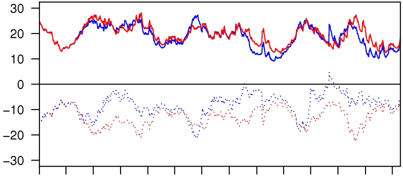
Precip. bias (mm/year)
mean: -100 mm/year

- Substantial negative bias in SIM_NRT w_2
- Associated with precipitation bias
- Can assimilation correct this?

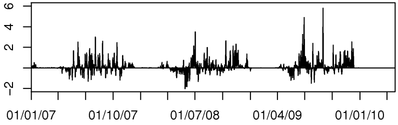
Impact on w_2



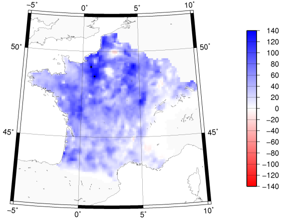
Mean daily w_2 (mm) - SIM_DEL (black), SIM_NRT (red), SIM_ASCAT (blue)



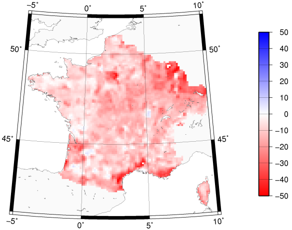
Bias / RMSD in w_2 (mm) - SIM_NRT (red), SIM_ASCAT (blue)



Mean daily analysis increment (mm)



Net increment (mm / 3.5 years)



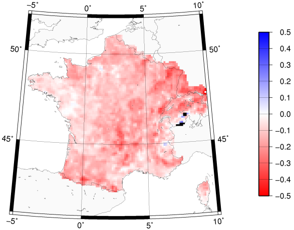
w_2 bias (mm)

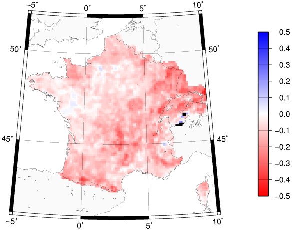
Impact on bias

SIM_NRT

SIM_ASCAT

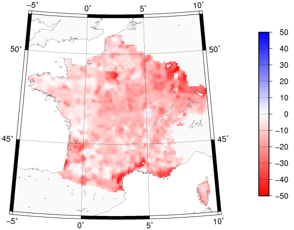
w_1 (mm)

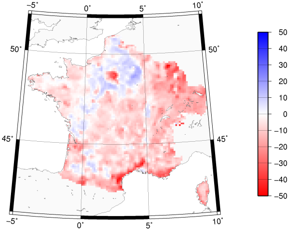




- Mean bias is reduced from -0.11 to -0.10 mm
  net reduction: 94% of grid-cells with ASCAT data

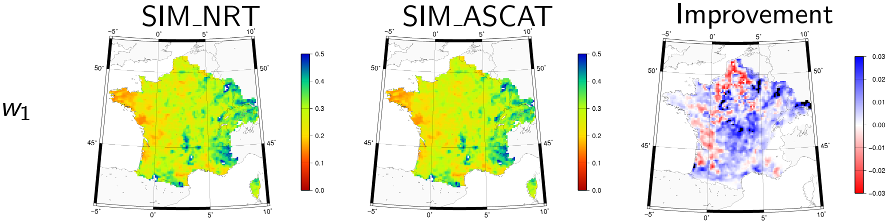
w_2 (mm)



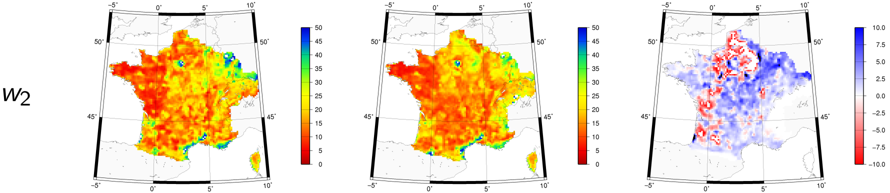


- Mean bias is reduced from -13.3 to -7.9 mm
  net reduction at 89% of grids-cells with ASCAT data

Impact on RMSD

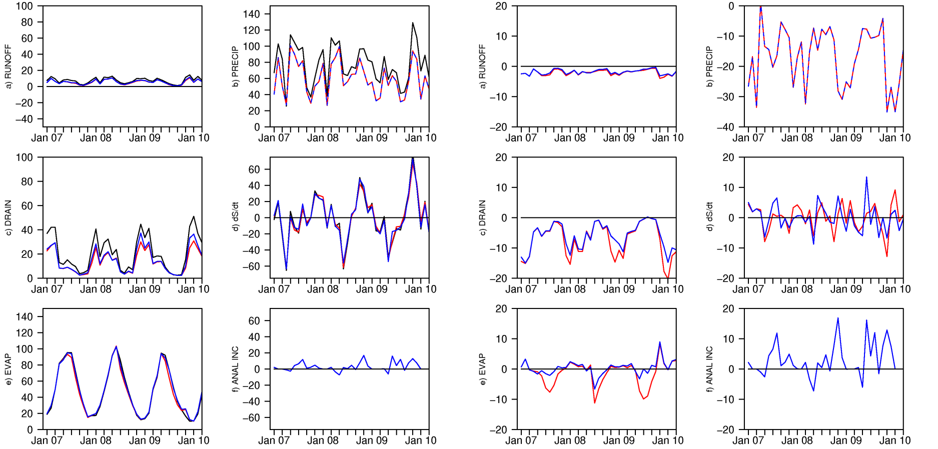


- Mean reduced from 0.283 to 0.279 mm
  reduction at 71% of grid-cells with ASCAT data



- Mean reduced from 18.1 to 17.6 mm
  reduction at 69% of grid-cells with ASCAT data

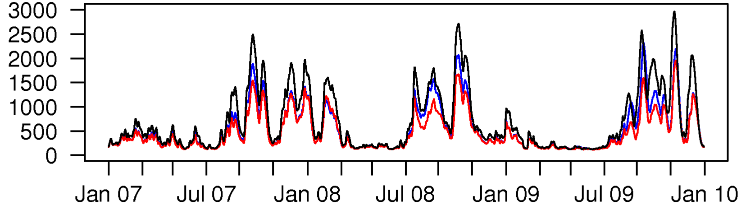
Impact on surface water balance



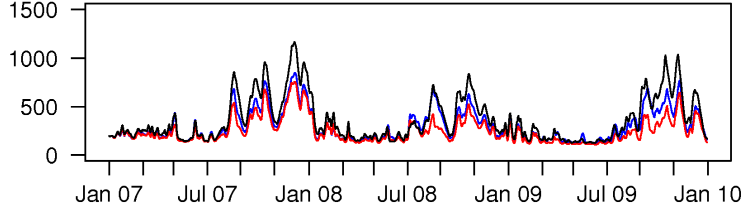
Water balance terms (mm/month)   Difference from SIM_DEL (mm/month)

SIM_DEL (black), SIM_NRT (red), SIM_ASCAT (blue)

Impact on river discharge



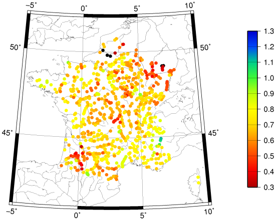
River Seine at Poses

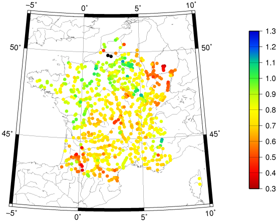


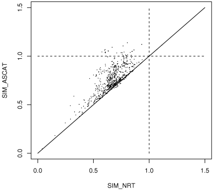
Loire River at Montjean sur Loire

Discharge ($m^3 day^{-1}$) from SIM_DEL (black), SIM_NRT (red), SIM_ASCAT (blue)

Discharge Ratio

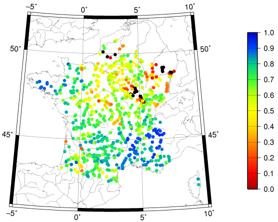




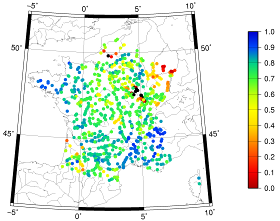


- Ratio $= Q_{sim}/Q_{ref}$
- Mean increased from 0.68 to 0.76
- Error in ratio decreased at 88% of stations

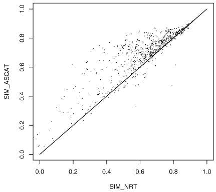
Nash-Sutcliffe Efficiency



SIM_NRT



SIM_ASCAT



- $E = 1 - \frac{\sigma_{t=1}^{T}(Q_{sim}^{t} - Q_{ref}^{t})^2}{\sigma_{t=1}^{T}(Q_{ref}^{t} - \bar{Q}_{ref}^{t})^2}$
- Mean increased from 0.62 to 0.68
- 82% of stations are improved

Conclusions

- The ASCAT SDS appears to be provide an accurate observation of changes in near-surface soil moisture
- Good temporal fit to in situ soil moisture observations at the SMOSMANIA sites
- Good temporal fit to soil moisture simulated by SIM over France
- Assimilation into SIM reduces the dry bias associated with the biased precipitation forcing
  - Reduces the bias in the soil moisture, water budget, and river discharge
  - ....but, is it doing this for the right reasons???
- Land-surface models are a valuable tool for evaluating novel remotely sensed soil moisture products

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For further details see H-SAF report:
http://hsaf.meteoam.it/documents/reference/HSAF_AS_09_01_report.pdf